STAFF REPORT

SUPPLY AND COST OF ALTERNATIVES TO MTBE IN GASOLINE

TECHNICAL APPENDICES

Refinery Modeling Task 1:
Specifying Scenarios and Methodology

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Evaluating the Cost and Supply of Alternatives to MTBE in California's Reformulated Gasoline

Project Report

REFINERY MODELING

TASK 1: SPECIFYING SCENARIOS AND METHODOLOGY

Prepared for

California Energy Commission

by

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under

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1. INTRODUCTION

MathPro Inc. is pleased to submit to the California Energy Commission (CEC) this report covering work performed for CEC under Subcontract CM6006W3 (Contract 500-96-012).

This subcontract covers the Refinery Modeling activity in CEC's larger project to evaluate the cost and supply of alternatives to MTBE in California's reformulated gasoline. The primary purpose of the Refinery Modeling activity is to estimate the economic effects on the California refining sector (e.g., incremental operating costs, new capital investments, etc.) of the proposed ban on MTBE in all gasoline consumed in California (referred to here as CARB RFG). The economic effects are to be estimated by formal modeling of the California refining sector, with an established computer-based refinery modeling system (employing *linear programming* (LP), an optimization technique widely used to analyze refining economics). The refinery modeling system of choice is **ARMS**, a proprietary product of MathPro Inc.

The Refinery Modeling activity comprises three tasks:

- **Task 1** Specify the policy scenarios analyzed and the methodology used in the Refinery Modeling activity

- **Task 2** Calibrate the refinery model used in this activity, to conform to aggregate operations of the California refining sector in the 1997 Summer season

- **Task 3** Analyze the specified scenarios using the calibrated refinery model

The primary work product of each task is a project report.

This report covers Task 1. It comprises six sections, including this one.

Section 2 defines important terminology and lays out the various *policy scenarios*.

Section 3 discusses key elements of the *refinery modeling methodology*.

Section 4 discusses *data requirements* for the refinery modeling and indicates the sources of the required data.

Section 5 discusses the *attributes that make LP the method of choice* for analyzing refining economics in studies such as this one.

Section 6 offers a *brief description of the refinery modeling system* used in this study.

The appendix is a copy of the survey questionnaire sent by CEC to California refiners as part of the data gathering process.

2. SCENARIOS TO BE ANALYZED

This section defines essential terminology regarding scenarios to be analyzed in this study and specifies the individual reference and policy scenarios to be analyzed.

2.1 DEFINITIONS

The *reference scenarios* denote (i) business-as-usual in the California refining sector – that is, continued MTBE use in the future time periods of interest, consistent with relevant federal and California laws and regulations now in effect (and with no new laws or regulations that affect MTBE use) – and (ii) business-as-usual, but with HR 630 (the Bilbray bill) in place. (HR 630 is under consideration in the U.S. Congress. Its effects are described below).

Each *policy scenario* denotes a specific set of assumptions regarding possible legislative or regulatory actions that would affect the economics of replacing MTBE.

Analyzing each policy scenario involves a set of refinery modeling runs, or *cases*, where each case corresponds to a unique combination of (1) a *replacement oxygenate* and (2) a *time period*.

A *replacement oxygenate* is a particular oxygenate that could replace MTBE in CARB RFG, chosen from this set:

- Ethanol
- ETBE
- TBA (tertiary butyl alcohol)
- Mixed refinery-produced oxygenates (in proportions determined by the refinery modeling)

Candidates for inclusion in the mixed refinery-produced oxygenates stream are ETBE, TAME, TBA, DIPE, and higher mixed ethers, e.g., as produced by the Neste Oy NeXTAME® process.

The reference and policy scenarios cover two time periods: *intermediate-term* and *long-term*.

- *Intermediate-term* is the earliest time period in which the refining industry could end MTBE use with short-lead-time measures such as de-bottlenecking, retro-fitting, and changes in service in refining, blending, oil movement, and distribution facilities.

  The intermediate term is the time period in which the supply of the given replacement oxygenate reaches a new equilibrium state that supports the additional demand induced by the proposed ban on MTBE in CARB RFG. (Thus, the calendar time period marking the intermediate term may differ from one replacement oxygenate to another.)

- *Long-term* is the earliest time period in which the refining industry could end MTBE use with long-lead-time and possibly large-scale capital investments (e.g., new process capacity) in refining, blending, oil movement, and distribution oxygenate facilities.

  The long term is the time period in which the refining sector completes its response to the proposed ban on MTBE use – through investment in new facilities – and reaches a stable new configuration.

Analyzing each policy scenario – corresponding to a specific set of assumptions regarding possible legislative or regulatory actions – calls for processing up to eight cases with ARMS (the refinery LP modeling system): *four replacement oxygenates* in each of *two time periods*.

2.2 POLICY ASSUMPTIONS

Each policy scenario denotes a unique combination of an *MTBE ban* assumption and an *oxygenate policy* assumption. CEC has specified two MTBE ban and six oxygenate policy assumptions.

- **MTBE Ban**

  - *California Ban on MTBE*

    California bans MTBE use in CARB RFG.

  - *Federal Ban on MTBE*

    In addition, the federal government bans MTBE use throughout the USA, in both conventional gasoline (CG) and reformulated gasoline (RFG).

- **Oxygenate Policy**

  Current Laws and Regulations

  Existing California and federal laws and regulations pertaining to gasoline manufacture remain in effect; but no additional ones.

  HR 630 in Effect

  Congress passes HR 630, ending the federal mandate for oxygenate in gasoline supplied to the federal non-attainment regions in California. Consequently, refiners may produce CARB RFG with oxygen content as low as zero in the Summer season, throughout the state.

  ♦

  Ethanol Rvp Waiver

Gasoline containing 10 vol% ethanol (3.5 wt% oxygen) enjoys a 1 psi Rvp waiver – that is, such gasoline may have an Rvp 1 psi higher than the Rvp standard otherwise applicable. In particular, the ethanol Rvp waiver changes the Rvp standard to $\leq$ 8.0 psi for CARB RFG containing 10 vol% ethanol.

No Tax Credits for Ethanol or ETBE

The existing federal tax credits granted to refiners and blenders of gasoline containing ethanol or ETBE are not extended after they expire in 2000.

No Tax Credits & HR 630

The existing federal tax credits described above expire and HR 630 passes.

No Tax Credits & Ethanol Rvp Waiver

The existing federal tax credits described above expire and ethanol enjoys the 1 psi Rvp waiver in California or throughout the USA (depending on the primary policy assumption in a given scenario).

Thus, for example, one policy scenario denotes the combination *California Ban on MTBE* and *Current Laws and Regulations*; another denotes *Federal Ban on MTBE* and *Current Laws and Regulations*; a third denotes *California Ban on MTBE* and *HR 630 in Effect*; and so on.

2.3 REFERENCE AND POLICY SCENARIOS

Exhibit 1 (next page) lists the reference and policy scenarios covered in the Refinery Modeling activity. In Exhibit 1, each line denotes a policy scenario, and each **X** denotes a specific replacement oxygenate for the indicated scenario.

As Exhibit 1 indicates, the Refinery Modeling activity encompasses two (2) reference scenarios, twelve (12) policy scenarios, and a total of seventy six (76) cases (refinery model runs).

2.4 PRIMARY RESULTS OF THE ANALYSIS

From the analysis of the various reference and policy cases, we will generate – for each policy scenario – intermediate term and long term estimates of:

- *Incremental costs*, including refinery operating and ancillary costs, refinery capital costs, import costs, and the social cost of changes in fuel economy associated with each replacement oxygenate;
- *Refining sector investments* for additional process capacity required with each

replacement oxygenate;

- *Refining sector utilization*, in terms of crude runs and production volumes of refined products meeting California standards; and

- *Average properties* of the CARB RFG and conventional gasoline pools produced in the California refineries, including (i) the gasoline properties registered in the CARB Predictive Model, (ii) Driveability Index (DI), and (iii) energy content.

These estimates will constitute the primary results of the Refinery Modeling activity.

Exhibit 1: Reference and Policy Scenarios for Refinery Modeling

		Replacement Oxygenates				
	Scenarios	MTBE	EtOH	ETBE	TBA	MRE
Reference Assumptions						
	Business as Usual (MTBE Use)	X				
	Business as Usual & HR 630 in Effect	X				
Policy Assumptions						
California Ban on MTBE	Current Laws and Regulations		X	X	X	X
	HR 630 in Effect		X	X	X	X
	Ethanol Rvp Waiver		X			
	No Tax Credits for EtOH or ETBE		X	X		X
	No Tax Credits and HR 630 in Effect		X	X		X
	No Tax Credits and EtOH Rvp Waiver		X	X		X
Federal Ban on MTBE	Current Laws and Regulations		X	X	X	X
	HR 630 in Effect		X	X	X	X
	Ethanol Rvp Waiver		X			
	No Tax Credits for EtOH or ETBE		X	X		X
	No Tax Credits and HR 630 in Effect		X	X		X
	No Tax Credits and EtOH Rvp Waiver		X	X		X

3. REFINERY MODELING METHODOLOGY

This section provides a brief overview of the refinery modeling methodology for Task 2 (calibration) and Task 3 (analysis of scenarios) of the Refinery Modeling activity. The section covers five topics.

1. Focus on the Summer season
2. Modeling California refineries with an aggregated model
3. Sequence of analytical steps in the methodology
4. Balancing domestic production, imports, and exports
5. Computing primary results of the analysis

3.1 FOCUS ON THE SUMMER SEASON

All of the refinery modeling runs in Tasks 2 and 3 apply to the Summer gasoline season only (May through August). In any given refinery, Summer gasoline is more costly to produce and requires more intensive use of capital stock than Winter gasoline. Any technical constraints on a given refinery's gasoline-making capability are most severe in the Summer season. In particular, the production cost and volume implications of replacing MTBE in CARB gasoline would be more severe in the Summer than in the Winter.

> The primary cause of the seasonal effect on refining economics is the gasoline Rvp standard, which is lower (more stringent) in the Summer than in the Winter.

3.2 MODELING AGGREGATE REFINING CAPACITY

Exhibit 2 lists the California refineries represented in the Refinery Modeling activity. These thirteen refineries account for more than 93% of the crude oil processing capacity in the California refining sector and virtually all capacity for producing CARB RFG.

The methodology for Tasks 2 and 3 employs a custom-developed representation (within the ARMS modeling system) of the aggregate refining process capacity of the refineries listed in Exhibit 2. (For brevity, we use the term **CALAGG** to denote this aggregate of California refining capacity.) Within ARMS, CALAGG refining capacity appears as one "aggregate refinery". The aggregate refinery is a model; it represents a single refinery that

- runs a crude oil slate matching the aggregate crude oil slate actually run in CALAGG;
- produces a product slate with volumes and properties consistent with current or forecast production in CALAGG; and
- has a process unit capacity profile and average process capabilities corresponding to those in CALAGG.

Exhibit 2: California Refineries Represented

Company	Location	Capacity (K Bbl/day)
ARCO Products Co.	Carson	255
Chevron USA Products Co.	El Segundo	258
	Richmond	225
Exxon Co. USA	Benicia	128
Kern Oil & Refining Co.	Bakersfield	21.4
Mobil Oil Corp.	Torrance	130
Shell Martinez Refining Co.	Martinez	155.2
Texaco Refining & Marketing	Bakersfield	57.8
	Wilmington	91.7
Tosco Refining Co.	Avon	156
	Rodeo/Santa Maria	103.6
	Wilmington	118.8
Ultramar Diamond Shamrock	Wilmington	68
Total		**1768.5**

Note: **Capacity** refers to crude oil charge rate.

One can think of an aggregate refinery as a representation of totally coordinated operation of the individual refineries in the specified refining sector (in this instance, CALAGG). In this idealized situation, refineries trade intermediate refinery streams, blendstocks, and products so as to make optimal use of all refining capacity, process by process, regardless of the refinery(s) in which the processing capacity resides.

Considerable trading of this kind actually occurs, but in volumes limited by physical and institutional barriers and by the capabilities of the capital stock in place. That is, an aggregate refinery represents inter-refinery trading beyond what can actually take place.

Consequently, results of analyses using an aggregate refinery model tend to indicate somewhat higher aggregate profit contributions and/or lower production costs and capital investments than actually would occur for a given set of market conditions and regulatory requirements. This tendency is one form of a modeling phenomenon known as "over-optimization". Over-optimization is characteristic of all analysis of refining operations that involves modeling aggregate refining capacity.

Good modeling practice can limit the effects of over-optimization and produce useful results for planning and policy recommendations. Indeed, refinery LP models representing large aggregates of refining process capacity (such as CALAGG) have been used to support development of all federal standards for motor fuels and have yielded prior estimates of average refining costs reasonably close to the industry's average realized costs.

Use of an aggregate refinery model – as opposed to modeling each individual refinery or regional refining center – is dictated by the funding and time available for the Refining Modeling activity. However, analysis with the CALAGG aggregate model should provide a good indication of the average incremental costs and volume effects of banning MTBE use and of the *relative* costs – state-wide – of replacing MTBE under the various policy scenarios.

More disaggregated modeling would yield more detailed (and perhaps more valid) estimates of the costs associated with MTBE replacement.

> For example, an individual refinery would have its own unique cost of producing CARB RFG without MTBE in any given scenario. That cost would depend, in part, on the refinery's own capital stock, operating requirements, and product slate.

3.3 FOUR STEP METHODOLOGY

Our technical approach, or methodology, for the refinery modeling analysis comprises four steps:

- in Task 2

1. Develop the aggregate refinery representation of CALAGG.

2. Calibrate ARMS so that the aggregate refinery conforms to key aspects of reported CALAGG operations in the 1997 Summer season.

- in Task 3

3. Develop and analyze the Reference Scenario cases, representing CALAGG operations under the two reference scenarios defined in Exhibit 1.

4. Develop and analyze the Policy Scenario cases, representing CALAGG operations under the twelve policy scenarios defined in Exhibit 1.

Following is a brief discussion of each step.

3.3.1 Represent the Aggregate Refinery in ARMS

Using the ARMS database, data in published sources, and data collected by CEC from the California refineries, we will establish the CALAGG aggregate refinery in ARMS.

The aggregate refinery will reflect CALAGG operations reported for the 1997 Summer season – including aggregate refining process capacities (by process unit), capacity utilization (by process unit), crude oil slate, product slate, gasoline grade splits, Class B and C gasoline splits, prices for crude oil and refined products, product specifications, and average properties of the CARB RFG and conventional gasoline pools produced by California refineries.

3.3.2 Calibrate ARMS to Summer 1997 Operations

Calibration demonstrates the validity, for the study at hand, of the ARMS refinery LP model and derives certain technical data elements for use in the subsequent steps.

Calibration involves adjusting technical data elements (e.g., gasoline blendstock properties, process yields and stream qualities, process unit capacity factors, etc.) in the ARMS database such that the ARMS model yields solution values that match with sufficient precision certain key measures of refinery operations in the calibration period (Summer 1997, in this instance). Once we accomplish this matching, we "freeze" the data elements for the subsequent steps.

Key measures for the calibration include reported product volumes, purchased blendstock volumes, gasoline pool composition, and capacity utilization of various refining processes. In this study, calibration will also focus on certain average properties of the CARB RFG and CG pools produced during the 1997 Summer season:

- Sulfur content
- Benzene content
- Oxygen content
- The T_{50} temperature in the gasoline distillation curve
- The T_{90} temperature in the gasoline distillation curve

These gasoline pool properties are independent variables in the CARB Predictive Model, which estimates vehicle emissions of NOx, VOC, and toxics, as functions of gasoline properties.

3.3.3 Analyze Reference Cases

The reference cases – representing business-as-usual operations in the Summer season in the intermediate term and long term periods – define the baseline for the subsequent analysis of the policy cases. Results of the reference case analysis constitute estimates of baseline refinery operations, product out-turns, and costs. Comparison of these baseline values with corresponding values generated in the analysis of policy scenarios provides estimates of the costs and technical implications of the various policy scenarios. In analyzing the reference cases, we will

- ♦ use the same slate of crude oils as the CALAGG refineries processed in Summer 1997; and
- ♦ use the CARB Predictive Model to calculate the emission reductions of gasoline pools produced by the aggregate refinery.

The reference cases will incorporate forecasts provided by CEC of the demand for refined products in California (and in the portions of adjoining states now served by California refineries) in the intermediate term and long term time periods.

3.3.4 Analyze the Policy Cases

The policy cases, defined in Exhibit 1, represent CALAGG operations under each policy scenario (for each indicated combination of time period and replacement oxygenate). In analyzing the policy cases, we will

- ♦ use a 15% rate of return on investment in computing the magnitude of capital investment in new process capacity and a 10% rate of return on investment in computing the per barrel costs of capital recovery;
- ♦ increase the capital charge factors for new process capacity needed to meet Summer, but not Winter, standards, such that Summer operations alone recover all capital charges (capital recovery and return on capital);
- ♦ use the same slate of crude oils as the CALAGG refineries processed in Summer 1997;
- ♦ use the CARB Predictive Model to calculate the emission reductions of gasoline pools produced by the aggregate refinery; and
- ♦ assume no price elasticity of demand for refined products.

In addition, we will assume that the refining sector's response to a ban on MTBE would involve an optimal combination of (i) advanced processing techniques with existing process capacity and (ii) investments in new process capacity using process technology now in commercial use or being offered for commercial use.

Most of the policy scenarios are neutral with respect to air quality, because they entail conforming to existing standards. But the scenarios involving the ethanol Rvp waiver produce an adverse effect on air quality, because VOC emissions increase with increasing Rvp. For these scenarios, the magnitude of the air quality degradation stemming from the ethanol Rvp waiver will be estimated as part of the overall CEC study, but not within the Refinery Modeling activity.

3.4 BALANCING PRODUCTION, IMPORTS, AND EXPORTS OF REFINED PRODUCTS

The analysis of the policy cases will accommodate – but not require – certain prospective changes in CALAGG operations:

- ♦ Reduced crude runs (relative to the Summer 1997 crude run);
- ♦ Reduced product out-turns (relative to the Summer 1997 out-turn);
- ♦ Imports of refined products (e.g., CARB RFG, diesel fuel, etc.) or blendstocks, to the extent economic or necessary (because of technical constraints in CALAGG) to meet forecast demand for CARB RFG and (perhaps) other products; and
- ♦ Exports of refined products or unfinished oils ("distressed cargoes"), to the extent economic or necessary to comply with a ban on MTBE use while meeting all other California product specifications.

This is an important aspect of the refinery modeling methodology, and it merits some discussion. CEC and other close observers of the California refining sector have expressed concern that a ban on MTBE use would not only increase the *cost* of producing CARB RFG but also reduce the total *volume* of CARB RFG that California refiners could produce (while meeting existing product specifications and environmental standards).

Any shortfall in California production of CARB RFG would have to be made up by imports of CARB RFG[1] (from the U.S. Gulf Coast or offshore sources). At the same time, technical and economic considerations might lead California refiners to export some volumes of refinery streams or finished products, such as pentanes and/or gasoline not meeting CARB standards. In this situation, the economics of CARB RFG supply would be determined by the interplay between the aggregate cost structure of the California

[1] In this context, we use CARB RFG to denote either CARB gasoline itself or any "CARBOB". A CARBOB is a base non-oxygenated gasoline, which may be blended with a specific oxygenate to produce on-spec CARB RFG.

refineries, the price-volume relationships for imported CARB RFG and various refinery inputs, and the cost-volume relationships for exported refinery outputs.

We address this possibility explicitly in the refinery modeling work. Specifically, the ARMS model will represent not only the aggregate refinery but also

- *Imports* of CARB RFG and/or gasoline blendstocks (alkylate, raffinate, and reformate);

- *Exports* of conventional gasoline and/or pentanes.

Solutions to the extended model will indicate (i) shortfalls (if any) in domestic (in-state) production of CARB RFG; (ii) volumes of all in-state production, imports (if any), and exports (if any); and (iii) market-clearing marginal costs of gasoline and other refined products.

Extending the aggregate refinery model in this way takes the analysis beyond the realm of conventional refinery modeling.

Exhibit 3 summarizes this aspect of the methodology. As the exhibit indicates, certain supply functions and demand functions are part of the input to the extended aggregate refinery model in ARMS. The supply functions for the replacement oxygenates are being developed by the Oxygenates Availability activity of the CEC project. The other supply functions and the demand functions are being developed in the California Import Capability activity.

3.5 COMPUTING PRIMARY RESULTS OF THE ANALYSIS

The primary results of the analysis comprise, for each policy case, the following elements:

- Incremental Costs (¢/gal)
  - Refinery operating costs (variable, or direct, refining costs)
  - Refinery capital charges (capital recovery and return on investment)
  - Import costs (for imported gasoline, other products, blendstocks, and refinery inputs)
  - Refinery ancillary costs (storage, blending, oil movement costs)
  - Fuel economy (mileage) change

- Refining Sector Investment ($MM) – for new process capacity

- Refining Sector Utilization (Bbl/day)
  - Domestic (California) production of gasoline, diesel, and other products
  - Domestic crude runs

- Average Gasoline Pool Properties
  - CARB Predictive Model properties
  - Driveability index
  - Energy Density

Exhibit 3: Balancing In-State Production, Imports, and Exports

For each policy case,

- ARMS inputs include
  - Forecasts of in-state and out-of-state demand for refined products (from CEC)
  - Estimated price-volume relationships (*"supply functions"*) for imported gasoline, replacement oxygenate, and specified gasoline blendstocks (alkylate, raffinate, reformate)
  - Estimated cost-volume relationships (*"demand functions"*) for exported conventional gasoline and refinery excess streams (pentanes)
- ARMS computes economic optimal solution, depicting the equilibrium between in-state production, imports, and exports of refined products
- ARMS outputs include
  - Capacity utilization in the California refineries
  - Volumes of CARB RFG and other refined products produced by California refineries
  - Volumes of imported streams (by type)
  - Volumes of exported streams (by type)
  - Market-clearing marginal costs of CARB RFG and other products

Following are brief comments on the computation of results from the outputs generated by ARMS for the reference and policy cases.

3.5.1 Incremental Costs

For each policy case, the total incremental costs (per gallon) of removing MTBE from CARB RFG is the sum of the four cost elements listed above. In turn, each of these cost elements is the *difference* between the estimated costs of (i) producing CARB RFG without MTBE, with the given policy scenario and replacement oxygenate, and (ii) producing CARB RFG under the corresponding reference scenario.

All of these costs are in cents per gallon of CARB RFG. The costs are *time-specific*; they apply to the Summer season of the indicated time period.

Refinery operating costs are the per-gallon variable, or direct, costs registered in the aggregate refinery (e.g., crude oil and unfinished oils, purchased utilities, catalysts and chemicals, etc.).

Refinery capital charges are the per-gallon costs registered in the aggregate refinery for recovery of capital invested in new process capacity, with a 10% rate of return.

Import costs are the costs of imports of CARB RFG and gasoline blendstocks (net of revenues from exports of conventional gasoline and other refinery outputs).

Refinery ancillary costs denote costs that California refineries would likely occur in complying with a ban on MTBE use but that are not registered in a refinery LP model. These costs could include capital charges for incremental tankage, inventory, and blending facilities, and associated operating expenses. The reported values for ancillary costs are our estimates, which are based on prior discussions with people in the refining refinery.

Mileage loss is the cost to California consumers of the difference in fuel economy (average miles/gallon) between CARB RFG produced without MTBE (policy case) and with MTBE (reference case).

> A gasoline's fuel economy is proportional to its energy density (expressed in MM BTU/Bbl or in M BTU/gal). Physical considerations dictate that energy density decreases with increasing oxygen content, decreasing distillation temperatures (i.e., T_{50} and T_{90}), and increasing RVP.
>
> ARMS captures all of these effects, and computes the energy density (in MM BTU/Bbl) of each gasoline pool, along with the pool's Predictive Model properties.

We use the following formula to estimate the cost *to California consumers* of mileage losses indicated in the policy cases:

$$\Delta \text{ Fuel economy cost (¢/gal)} = \Delta \text{ ED (\%)} * [\text{ARP (¢/gal)} + \text{IRC (¢/gal)}]$$

where

Δ ED is the change in energy density with respect to the reference gasoline pool, expressed as a percentage of the energy density of the reference gasoline pool;

ARP is the adjusted average retail price of gasoline in California (*excluding* federal and state taxes) – to be provided by CEC for the Summer 1997 season; and

IRC is the incremental refinery operating cost and capital charge in the given case.

This formula is consistent with EPA's approach in assessing the costs of the federal RFG program.

3.5.2 Refining Sector Investment

Refining sector investment denotes capital investments in the CALAGG refineries for new process units and expansions of existing units. They correspond to solution values registered for the aggregate refinery and include on-site and off-site elements.

3.5.3 Refining Sector Utilization

Refining sector utilization encompasses several measures of the extent to which existing California refining capacity would remain employed in the face of a ban on MTBE use. The measures – crude runs in California refineries and production in California refineries of gasoline (CARB RFG and conventional), diesel fuel, and other products – correspond to values registered in the aggregate refinery.

3.5.4 Gasoline Properties

The gasoline properties reported for each policy case are absolute, not incremental, values. ARMS produces all of these values directly, except for DI. We estimate DI for each case using the distillation curve computed by ARMS for that case and the following formula for DI:

$$DI = 1.5 \text{ x } T_{10} + 3.0 \text{ x } T_{50} + T_{90}$$

Txx denotes the temperature (°F) at which xx vol% of the gasoline evaporates in the standard laboratory distillation test.

4. DATA FOR REFINERY MODELING

This section deals with the data requirements for the refinery modeling described in Sections 2 and 3. The discussion covers three topics.

1. Data classes
2. Data sources
3. Special survey of California refiners

4.1 CLASSES OF DATA

Refinery modeling draws upon two broad classes of data (i.e., numerical values that characterize refinery operations).

Techno-economic values describe (in engineering terms) (i) refinery inputs and outputs (e.g., crude oils, refined products), process unit capacity, and the economics of capital investment; and (ii) the performance of individual refining processes, in terms of input/output coefficients (e.g., process yields, energy consumption, etc.), refinery stream properties, and blendstock qualities.
Techno-economic values may be refinery-specific, or they may represent region-wide (as in this study) or industry-wide averages.

> ARMS contains a set of representative techno-economic values, including all elements needed to create the CALAGG aggregate refinery. Some of these elements will be modified in the calibration step (Task 2), as described in Section 3.3. After calibration, we will "freeze" the resulting set of techno-economic values for the subsequent analysis of the reference and policy cases (Task 3).

Boundary values denote external conditions that refining operations must satisfy in a given location and time period, such as crude oil availabilities, product demands, product specifications, crude and product prices, and environmental standards.[2] For prior time periods (e.g., Summer 1997, the calibration period), boundary values usually denote "real" values, drawn from published reports on refining operations. For future time periods (e.g., the intermediate term and long term periods), boundary values are explicit forecasts. (In this context, the estimated supply functions and demand functions discussed in Section 3.4 and Exhibit 3 are boundary values.)

> In developing and calibrating the aggregate refinery model, we will use boundary values for the Summer 1997 period that are aggregated across all CALAGG refineries and averaged over the four months of the period. No refinery-specific values will be employed in the refinery modeling analysis.

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[2] We call these "boundary values" because they characterize streams that flow into or out of the refinery, i.e., across the refinery's boundaries.

CEC will derive the aggregated and averaged boundary values for the Summer 1997 period from (i) standard monthly reports submitted by the refineries (e.g., CEC M07, EIA 810) and (ii) the returns from a special survey of California refineries conducted for this study (discussed in Section 4.3).

In analyzing the reference and policy cases, we will use boundary values for the intermediate term and long term periods that incorporate (i) forecasts of California demand for CARB RFG and other refined products and (ii) estimated supply functions and demand functions for imported and exported streams, respectively. These boundary values will be the *only* inputs to the aggregate refinery model that are unique to the reference and policy cases.

4.2 DATA SOURCES

Data required for the refinery modeling analysis will come from six main sources:

1. The existing ARMS database;

2. Publications (e.g., the annual world-wide refining surveys of the *Oil & Gas Journal*; the annual *Oil & Gas Databooks*; the *Petroleum Supply Annual*, *Annual Energy Review*, and *Annual Energy Outlook*, all published by the U.S. Energy Information Administration (EIA), etc.);

3. Standard monthly reports submitted by California refiners to CEC (e.g.; CEC M07) and EIA (e.g., EIA 810) for the calibration period (Summer 1997);

4. A special one-off survey of California refineries regarding Summer 1997 operations, conducted by CEC for this study;

5. Forecasts, developed by CEC, of (i) California demand for CARB RFG and other refined products and (ii) out-of-state demand for conventional gasoline and other refined products, in the intermediate term and long term periods; and

6. Estimated supply functions and demand functions for specified import and export streams, developed in the Oxygenates Availability and California Import Capability activities

Exhibit 4 (next page) indicates the data sources that come into play in each step of the refinery modeling methodology, described in Section 3.3. (The numbers in the heading of Exhibit 4 correspond to the items above.)

Exhibit 4: Data Sources for the Refinery Modeling Methodology

		Data Source					
Methodology	**Data Values**	1	2	3	4	5	6
1. Develop Aggregate	Techno-Economic	X	X		X		
Refinery Model	Boundary	X	X	X			
2. Calibrate Aggregate	Techno-Economic	X			X		
Refinery Model	Boundary	X		X			
3. Analyze Reference Cases	Techno-Economic	X					
	Boundary	X				X	
4. Analyze Policy Cases	Techno-Economic	X					
	Boundary	X				X	X

4.3 Special Survey of California Refineries

As noted in Section 4.1, CEC has conducted a special survey of California refineries to support development and calibration of the aggregate refinery model. The survey sought techno-economic and boundary value data on actual refinery operations for the four months of the Summer 1997 season. All thirteen CALAGG refineries participated in the survey.

The survey employed a questionnaire designed by CEC and MathPro Inc. A copy of the questionnaire is appended to this report.

CEC will analyze the survey returns and convey the survey results aggregated across all refineries and averaged over the four month period.

CEC is treating the individual survey returns as confidential. CEC will not provide refinery-specific to the Refining Modeling activity.

5. LP AS THE METHOD OF CHOICE FOR REFINERY MODELING

This section explains why linear programming is the method of choice for the Refinery Modeling activity and, indeed, for most techno-economic analyses of refining operations.

5.1 TECHNO-ECONOMIC ANALYSIS AND LINEAR PROGRAMMING

Analyzing the economics of gasoline production – including (for example) the prospective costs of producing CARB RFG without using MTBE – calls for engineering (or *techno-economic*) analysis of the specific refinery or aggregate refinery of interest. Since the late '50s, the method of choice for conducting techno-economic analysis of refining operations has been formal, computer-based modeling with a *refinery LP model*.

> LP is the most widely used mathematical technique for optimization – that is, for finding the best solution (in an economic sense) to complex problems involving allocation of scarce resources across many competing activities.
>
> In refining operations, the scarce resources are the refinery's production facilities, raw materials, and process streams (e.g., blendstocks), and the competing activities are the refinery's manifold processing operations.

Virtually all refining companies use in-house, custom-configured LP models of their own refineries for (i) tactical and operations planning, (ii) monthly and weekly scheduling, and (iii) crude oil and product pricing analysis. Government agencies and private sector organizations use generalized refinery LP models (that can be adapted to represent specific refineries or refinery groupings) to estimate the effects on refining economics of proposed policies, regulations, and fuel standards.

5.2 LP'S UNIQUE VALUE FOR REFINERY MODELING

LP is indispensable for refinery modeling because:

- It embodies rigorous, robust, and efficient search procedures, which find the best solution from the set of all possible solutions to the case at hand.

- Results generated by an LP model contain two distinct but complementary classes of information -- *physical* (e.g., levels of activity for various processing options, flow rates, blend compositions, etc.) and *economic* (e.g., marginal prices, penalty costs, substitution rates, etc.).

  In this respect, LP stands alone. No other analytical method generates results of comparable breadth, depth, and analytical value.

- Powerful, reliable off-the-shelf software is available for most LP applications.

These attributes have important implications for analysis. First, LP modeling provides a rigorous means of comparing solutions to different scenarios, or cases. Because LP generates optimal solutions, one can compare solutions for different cases knowing that each solution is computed "to the hilt" in the same rigorous manner and is the best for the given case. Second, LP modeling both demands and facilitates simultaneous consideration of the economic and physical aspects of the problem at hand.

5.3 INFORMATION GENERATED BY A REFINERY LP MODEL

With a refinery LP model, experienced analysts can simulate how a refinery or group of refineries would operate – on an average day in a specified time period – to produce a specified product slate at minimum cost. These simulations yield not only descriptions of prospective refinery operations but also

- the total and marginal *refining costs* associated with the case at hand;
- *capital investment requirements* and *operational changes* called for by the case at hand;
- *properties* of the gasolines (and other refined products produced), for calculating emissions and other kinds of performance (e.g., fuel economy); and
- *marginal refining values* (or "*shadow prices*") for all refinery streams, including both internally produced and purchased blendstocks.

Solutions to sequences of LP modeling cases can trace out refinery supply functions and indicate the impacts on refining operations and economics of prospective changes in energy and environmental policy and regulation; crude oil and feedstock quality, price, and availability; product demand and specifications; and refining capital stock.

6. OVERVIEW OF ARMS

ARMS is a generalized refinery modeling system, developed by MathPro Inc. This section introduces ARMS. The discussion – very brief – covers four topics.

1. Applications
2. Main technical features
3. Basic modeling concepts
4. Special features

6.1 APPLICATIONS OF ARMS

ARMS is an established refinery modeling system, with a track record of use in numerous projects for private companies and government agencies, covering a range of issues including:

- Refining costs, investment requirements, and environmental performance of alternative gasoline formulations considered by the Ozone Transport Assessment Group (OTAG), chartered by EPA to recommend measures for improving air quality in the Ozone Transport Region of the U.S.;
- Refining costs, investment requirements, and environmental performance of alternative gasoline formulations for Maricopa County, Arizona, in support of the state's implementation plan for ozone control;
- Refining costs associated with reducing the sulfur content of conventional and reformulated gasolines to very low levels;
-
- Refining values of and prospective demands for ethanol as direct gasoline blendstock or oxygenate feedstock;
- Refining values of purchased gasoline blendstocks (including MTBE and other oxygenates), by region, refinery type, and season;
- Refining costs of producing reformulated gasolines to various regulatory standards and requirements in the U.S., Canada, and other countries;
- Refining economics of generating tradeable emissions credits by producing gasolines whose emissions performance exceeds regulatory requirements;
- Refining economics of lead phase-down and phase-out in various countries;
- Refining economics of producing additional volumes of petrochemical feeds;
- Economic impacts on the refining sector of new process technologies;

- Effects of changes in gasoline composition on refinery energy requirements;

- Refining values (in the U.S. and other countries) of various domestic and foreign crude oils (including crude blends in the Strategic Petroleum Reserve);

- Refining values of Alaskan North Slope (ANS) crude to Pacific Rim refiners (for the federal policy review that led to repeal of the ban on exporting ANS crude); and

- Effects on U.S. oil imports and refining economics of prospective octane-enhancing additives (e.g., MMT) for gasoline blending.

Some of these studies have made important contributions to the understanding of the economic effects of public policy initiatives affecting the refining sector.

6.2 TECHNICAL SUMMARY

ARMS is a PC-resident refinery modeling system. It is designed specifically to support policy analysis and business planning studies dealing with technical and economic responses of the refining industry (or individual refineries) to real or prospective changes in public policy, regulation, technology, and/or market conditions. Consistent with its purpose, ARMS represents the technology and economics of refinery operations in **engineering** (not econometric) terms.

ARMS comprises a linear programming (LP) model of refining operations; a library of crude oil assays; a database of techno-economic values describing refinery operations; and software for creating, operating, and reporting on refinery LP models.

> The LP model is expressed as a computer-readable **model statement**, specifying the model's mathematics and logic in symbolic form, independent of any data one might associate with the model and embody in its coefficients. The database contains techno-economic and boundary values, in tabular or relational form.

Linking the model statement to a specific set of techno-economic and boundary values produces a distinct **model instance**, or **case**, that ARMS processes and solves. (Typical analyses of policy and planning issues may involve creating and processing hundreds of cases.)

ARMS has custom-designed computer programs for managing the model statement; managing data; creating model instances (cases); solving models; and analyzing model solutions. The programs form an open, flexible, easy-to-enhance system, with links to spreadsheets and other external applications. By virtue of this design and implementation approach, ARMS supports both quick response analyses and longer-term analyses that call for modifying or extending the model statement (as in this study).

ARMS operates under Windows 95® and is implemented by means of fourth-generation optimization modeling software (an advanced modeling toolkit and a high-speed solver).

6.3 BASIC MODELING CONCEPTS

The ARMS LP model is a *static*, *process-oriented*, *disaggregated*, *optimizing* representation of the operations and economics of refining.

- *Optimizing*: Solutions to the LP model define optimal refining operations and economics for the specified refinery or refining aggregate and policy scenario.

- *Disaggregated*: ARMS represents refining facilities (that is, capital stock within refinery battery limits) at a user-specified level of disaggregation: an individual PADD or a group of PADDs (e.g., PADDs 1-3), a state, a group of similar refineries in a region or refining center (e.g., complex refineries in the Los Angeles center), or an individual refinery.

- *Process-oriented*: ARMS represents refining operations, process by process, in techno-economic or engineering (not econometric) terms.

- *Static*: ARMS represents an average day's operations of the specified refining aggregate or refinery in the specified time period (year and season), with no inter-temporal flows such as inventory build-up or draw-down.

The solution to an ARMS case defines a pattern of refining operations and a set of prices for feeds, products, and refinery process capacity that minimize aggregate refining cost or maximize aggregate profit contribution, for a given set of boundary values.

In this context, *profit contribution* is the difference

Product Revenues - Costs of (Crude + Other Inputs + Purchased Energy + Catalysts/Chemicals) - Investment Amortization

where the revenues and all of the cost items are per barrel of output and input (respectively), with fixed costs not considered.

The ARMS LP model is a partial equilibrium model. That is, the solution to an ARMS case simulates refining operations such that

- the market for each refined product clears at the computed prices;

- each refinery is in competition with all others in the given region; and

- all competitors have full information about the market.

Solutions to a given ARMS case define optimal refining operations in terms of:

- volumes consumed and marginal value of crude oils and purchased blendstocks;
- compositions and qualities of finished products blended to specification;
- aggregate capacity utilization and the marginal value of new capacity, by process;
- aggregate investment in new capacity;
- volumes produced and marginal cost of each finished product;
- marginal cost of each intermediate refinery stream and blendstock; and
- marginal cost of satisfying each individual specification, by blended product.

6.4 SPECIAL FEATURES

6.4.1 Process Representations

ARMS contains representations of not only the standard commercial refining processes but also prospective new processes and process options. Some of the new technologies are for producing oxygenates, oxygenated and reformulated gasolines, and low-sulfur gasolines and diesel fuels; others are for improving refining economics in general. Examples include olefin-maximizing FCC catalysts, FCC operations with residual oil feeds, depentanization of gasoline blendstocks, hydrotreating FCC gasoline via the OCTGAIN® process, and "under-cutting" FCC gasolines and reformates.

Because fluid catalytic cracking (FCC) operations are the most important single determinant of refining economics in conversion refineries and because FCC units have exceptional flexibility, ARMS contains an especially detailed representation of FCC operations. The representation covers various feedstocks (ranging from distillates to residual oils), catalyst types, operating modes, and conversion levels.

ARMS allows representations of three distinct gasoline pools – e.g., CARB RFG, federal Phase 2 RFG, and conventional (as in this study). Each pool may contain up to three gasoline grades (e.g., regular, mid-grade, and premium). ARMS honors specifications for each grade and for each pool represented.

6.4.2 Predictive Model and Complex Model Representations

ARMS contains built-in representations of (i) the federal Phase 2 Complex Model for certifying federal RFG and (ii) the California Predictive Model for certifying CARB RFG. Consequently, in ARMS solutions, the properties of the RFG pools (if any) comply with the relevant (federal or California) emission standards. We use the Predictive Model representation in this study.

Following is a brief overview of our procedure for building the Complex Model (CM) and the Predictive Model (PM) into ARMS.

First, we derived reduced form representations of the CM and the PM, in separated form.

A *reduced form* model captures in simple mathematical structure the main input/output relationships of a larger, more complicated model, with sufficient accuracy for the analytical purpose at hand.

A model in *separated* form comprises only single-variable functions. That is, none of the model's terms involve more than one independent variable – no cross products, quotients, etc. In this sense, the variables are separated.

The reduced form models for the CM and PM are sets of polynomial equations of the form:

$$ER_i = a_i + \Sigma_j (b_{ij}X_j + c_{ij}X_j^2)$$

Where **i** = emission category [VOC (total), NOx, Toxics]

j = gasoline property [Rvp, oxygen content, aromatics content, benzene content, olefins content, sulfur content, E200, E300]

ER_i = Emission reduction, category **i**

a_i = Constant term for emission category i

b_{ij} and c_{ij} = Coefficients of the first order and second order terms for emission category **i** and gasoline property **j**

Xj = Value of gasoline property **j** (computed in the LP model)

Estimating the reduced form models was itself a three-step procedure. We generated sets of 4,000 random gasoline "blends" (i.e., random combinations of the gasoline properties), for each reduced form model. (We imposed no functional relationships or constraints to restrict the random combinations of gasoline properties to "feasible" gasoline blends.) Then, for each of the 4,000 random blends in each set, we used the "real" CM or PM (as appropriate) to calculate the corresponding emissions changes. Finally, we used standard regression analysis to estimate second order polynomial equations relating calculated emission changes to gasoline properties. (The estimated equations have $R^2 > 0.99$, meaning that they explain about 99% of the blend-to-blend variations in emission reductions.)

Second, we embedded the reduced form CM and PM models in the ARMS LP model.

Having the reduced form models in separated form is the key to this step. The reduced form models are nonlinear in the gasoline properties. But because they are separated, one can express them directly in LP's linear framework – as sets of *piece-wise-linear* functions, one for each gasoline property involved. In LP parlance, piece-wise-linear functions are called *Special Ordered Sets, Type 2* (**SOS2**).

We expressed the nonlinear reduced form equations for the CM and the PM as two discrete sets of SOS2s (one set for the CM; one for the PM) and added these functions to the ARMS refinery LP model.

We solve the refinery LP model containing the CM or PM using a commercial solver with SOS2 capability.

This discussion touches only on the highlights of the approach. Discussion of the details, some of which are of critical importance, is beyond the scope of this report. A full discussion is in *Fuel Reformulation*; Vol. 4, No. 2; March/April 1994; pgs 64-68.

APPENDIX

SPECIMEN SURVEY OF CALIFORNIA REFINERIES

Refinery Location:

Company:

Table 1: Process Unit Capacity and Capacity Utilization: Summer 1997

Process Type/ Flow Diag. Unit Name	Unit	Capacity in Terms of	Maximum Sustainable Capacity* (bbl/sd)	Actual Throughput** (bbl/sd)	Process Information	Notes
Crude Dist.						
	Atmospheric	Feed				
	Vacuum	Feed				
Conversion						
	Visbreaking	Feed				
	Coking	Feed				(1)
	Thermal Cracking	Feed				
	Fluid Cat Cracking	Feed				(2)
	Hydrocracking	Feed				(3)
Upgrading						
	Alkylation (HF or SA)	Product				
	Reforming #1	Feed				(4)
	#2	Feed				(4)
	C5/C6 Isomerization	Feed				(5)
	Dimer	Product				
	Polymerization	Product				
H2 Generation						
	Refinery-owned	Prod. (K scf/d)				(6)
	Captive, 3rd party-owned	Prod. (K scf/d)				(7)
	Other (purchases)	(K scf/d)				(8)
Hydrogen	Purification	Feed (K scf/d)				(9)
Oxy. Prod.						
	MTBE	Product				
	TAME	Product				

Refinery Location:

Company:

Table 1: Process Unit Capacity and Capacity Utilization: Summer 1997

Process Type/ Flow Diag. Unit Name	Unit	Capacity in Terms of	Maximum Sustainable Capacity* (bbl/sd)	Actual Throughput** (bbl/sd)	Process Information	Notes
Hydrotreating						
	LSR Naphtha	Feed				
	Reformer Feed	Feed				
	Distillate Desulfurization	Feed				
	Distillate Dearomatization	Feed				
	FCC Feed/Heavy Gas Oil	Feed				
	Resid	Feed				
	FCC Gasoline	Feed				
	Benzene Saturation	Feed				
	Other	Feed				
Other						
	Solvent Deasphalting	Feed				(10)
	Sulfur Recovery	Product				(11)
	Tail Gas Recovery	Product				
	Lube Oil	Product				
	C4 Isomerization	Feed				
	Aromatics Production	Product				
	Cogeneration	MegW				
	Other					

* Maximum sustainable daily capacity over the summer months, given quality of feeds.
** Average throughput for Summer 1997.

Notes:

(1) Indicate delayed, fluid, or flexi coking.
(2) Provide average conversion rate in percent.
(3) Provide hydrogen consumption in K scf/bbl of feed and operating pressure in psig.
(4) Provide unit pressure (psi) and average severity (RON).
(5) Indicate if recycle or once-through. Capacity should include internal recycle and recycle volume from downstream seperation units.
(6) Include capacity only of refinery-owned units. Report capacity in terms of K scf/d of hydrogen product.
(7) Provide capacity of third-party owned hydrogen units that are fully dedicated to your refinery.
(8) Provide average daily purchases of hydrogen from sources other than company-owned and dedicated third-party units.
(9) Include only if purification plant is a system separate from the hydrogen plant and is used for other streams. Capacity should be reported in terms of K scf/d of feed. Indicate purified hydrogen output as a percent of the volume of input streams.
(10) Report capacity in terms of long tons of product sulfur from sulfur plant.
(11) Report capacity in terms of long tons of product sulfur from tail gas unit only.

Refinery Location:

Company:

Table 2: Typical Feeds, by Unit: Summer 1997

Process Type/ Flow Diag. Unit Name	Unit	Typical Feeds					
		Boiling Range (°F) or Description	% of Charge	Boiling Range (°F) or Description	% of Charge	Boiling Range (°F) or Description	% of Charge
Conversion							
	Visbreaking						
	Coking						
	Thermal Cracking						
	Fluid Cat Cracking						
	Hydrocracking						
Upgrading							
	Alkylation (HF or SA)						
	Reforming #1						
	#2						
	C5/C6 Isomerization						
	Dimersol						
	Polymerization						
Hydrogen							
	Generation						
	Purification						
Other							
	Solvent Deasphalting						
	Sulfur Recovery						
	Tail Gas Recovery						
	Lube Oil						
	C4 Isomerization						
	Aromatics Production						
	Cogeneration						
	Other						

Company:

Refinery Location:

Table 3: Hydrogen Use and Feeds, by Hydrotreating Unit: Summer 1997

Measure	LSR Naphtha	Reformer Feed	Distillate Desulf-urization	Distillate Dearo--matization	FCC Feed/ Hvy. GO	Resid	FCC Gasoline	BenSat	Other
Hydrogen (scf/bbl)									
Charge									
Consumption									
Sulfur Removal (%)									
Reduction in:									
Octane -- RON									
MON									
Aromatics (% pt.)									
Olefins (% pt.)									
Improvement in:									
Cetane number									
#1 Feed									
Boiling Range (°F)									
% of Charge									
Sulfur Content (ppm)									
Cetane number									
Aromatics (vol %)									
Olefins (vol %)									
Octane -- RON									
MON									
#2 Feed									
Boiling Range (°F)									
% of Charge									
Sulfur Content (ppm)									
Cetane number									
Aromatics (vol %)									
Olefins (vol %)									
Octane -- RON									
MON									
#3 Feed									
Boiling Range (°F)									

Company:

Refinery Location:

Table 3: Hydrogen Use and Feeds, by Hydrotreating Unit: Summer 1997

Measure	LSR Naphtha	Reformer Feed	Distillate Desulf-urization	Distillate Dearo--matization	FCC Feed/ Hvy. GO	Resid	FCC Gasoline	BenSat	Other
% of Charge									
Sulfur Content (ppm)									
Cetane number									
Aromatics (vol %)									
Olefins (vol %)									
Octane -- RON									
MON									
#4 Feed									
Boiling Range (°F)									
% of Charge									
Sulfur Content (ppm)									
Cetane number									
Aromatics (vol %)									
Olefins (vol %)									
Octane -- RON									
MON									

Company:

Refinery Location:

Table 4: Gasoline Volume and Average Pool Properties, by Grade and Class: Summer 1997

Volume/ Property	California RFG			Arizona RFG			Conventional		
	Premium	Mid-Grade	Regular	Premium	Mid-Grade	Regular	Premium	Mid-Grade	Regular
Volume (bbl/d)									
Octane									
MON									
RON									
API Gravity									
RVP (psi)									
Oxygen (wt%)									
Aromatics (vol%)									
Benzene (vol%)									
Olefins (vol%)									
Sulfur (ppm)									
E200 (%)									
E300 (%)									
Butane content (vol%)									
Pentane content (vol%)									
Distillation (°F)									
IBP									
T10									
T30									
T50									
T70									
T90									
FBP									
Distribution of Oxygenates (vol%)*									
MTBE									
TAME									
Other									

Summer 1997 refers to the time period covering May 1 through August 31, 1997 (123 calendar days).

* Relative volume percent use of oxygenates -- sums to 100.

Company:

Refinery Location:

Table 5: Average Gasoline Blendstock Volume and Properties: Summer 1997

Blendstock	Volume*	Octane		API	RVP	Aromatics	Benzene	Olefins	Sulfur	E200	E300	Distillation (°F)						
	(bbl/d)	MON	RON	Gravity	(psi)	(vol %)	(vol %)	(vol %)	(ppm)	(%)	(%)	IBP	T10	T30	T50	T70	T90	FBP
Naphthas																		
Light Str. Run -- virgin																		
Light Str. Run -- desulf																		
Light coker -- virgin																		
Light coker -- desulf																		
Hydrocrackate																		
Light																		
Medium																		
Full range																		
Alkylate																		
Mixed																		
Propylene																		
Butylyene																		
Amylene																		
T90 controlled:																		
Mixed																		
Propylene																		
Butylyene																		
Amylene																		

Company:

Refinery Location:

Table 5: Average Gasoline Blendstock Volume and Properties: Summer 1997

Blendstock	Volume* (bbl/d)	Octane MON	Octane RON	API Gravity	RVP (psi)	Aromatics (vol %)	Benzene (vol %)	Olefins (vol %)	Sulfur (ppm)	E200 (%)	E300 (%)	Distillation (°F) IBP	T10	T30	T50	T70	T90	FBP
Reformate																		
Full range																		
Light																		
Heavy																		
Post-benzene satur.																		
Full range																		
Light																		
Post-T90 control																		
Full																		
Heavy																		
Other																		
Raffinate:																		
Full range																		
Light																		

Company:

Refinery Location:

Table 5: Average Gasoline Blendstock Volume and Properties: Summer 1997

Blendstock	Volume*	Octane		API	RVP	Aromatics	Benzene	Olefins	Sulfur	E200	E300	Distillation (°F)						
	(bbl/d)	MON	RON	Gravity	(psi)	(vol %)	(vol %)	(vol %)	(ppm)	(%)	(%)	IBP	T10	T30	T50	T70	T90	FBP
FCC Gasoline																		
Pre-desulfurization																		
Full																		
Light																		
Medium																		
Heavy																		
Post-desulfurization																		
Full																		
Medium																		
Heavy																		
Post-T90 control																		
Full																		
Heavy																		
Other																		

Company:

Refinery Location:

Table 5: Average Gasoline Blendstock Volume and Properties: Summer 1997

Blendstock	Volume*	Octane		API	RVP	Aromatics	Benzene	Olefins	Sulfur	E200	E300	Distillation (°F)						
	(bbl/d)	MON	RON	Gravity	(psi)	(vol %)	(vol %)	(vol %)	(ppm)	(%)	(%)	IBP	T10	T30	T50	T70	T90	FBP
Isomerate																		
Mixed																		
C5																		
C6																		
Dimate																		
Polymer Gasoline																		
N-Butane																		
Oxygenates																		
MTBE																		
TAME																		
Other Oxygenate																		
Other																		

Note: Stream properties should be reported with current level of butane control.

Summer 1997 refers to the time period covering May 1 through August 31, 1997 (123 calendar days).

* The entries in this column should sum to average daily gasoline production (all gasoline classes and grades).

Company:

Refinery Location:

Table 6: Jet, Distillate and Residual Fuel Oil Volume and Average Pool Properties: Summer 1997

Volume/ Property	Jet Fuel	Diesel Fuel CARB Low Aromatic	EPA Low Sulfur	Other High Sulfur	Residual Fuel Oil
Volume (bbl/d)					
API Gravity					
Sulfur (ppm)					
Nitrogen (ppm)					
Freeze Point (°F)					
Smoke Point (mm)					
Naphthalenes (vol%)					
Aromatics (vol%)					
Polynuclear Aromatics (vol%)					
Cetane Number (clear)					
Cetane Improver (ppm)					
Cetane Number (additized)					
Pour Point (°F additized)					
Pour Point Depressant (ppm)					
Distillation (°F)*					
IBP					
T10					
T30					
T50					
T70					
T90					
FBP					

Summer 1997 refers to the time period covering May 1 through August 31, 1997 (123 calendar days).
* As available.

Company:

Refinery Location:

Table 7: Crude Oil Volume and Properties: Summer 1997

Name	Volume (bbl/sd)	API Gravity	Sulfur (wt%)	Nitrogen (wt%)	Crude Diluent (vol%)		
					Pentanes	Natural Gasoline	Other
Total Crude Slate							
Alaskan							
North Slope							
Cook Inlet							
California							
Elk Hills							
Kern River							
Outer Continental Shelf							
San Ardo							
San Joaquin Heavy							
San Joaquin Light							
Ventura							
Wilmington							
Imports							

Summer 1997 refers to the time period covering May 1 through August 31, 1997 (123 calendar days).

Company:

Refinery Location:

Table 8: Inputs From Outside the Refinery Gate (other than crude oil)
Summer 1997

Description	Average Volume (bbl/sd)	Supply Source of Inputs			Boiling Range (°F)	API Gravity	Sulfur (ppm)	Inventory Drawdown*
		Other Calif. Complex	Calif. Non-complex	Outside Calif.				
Natural Gas (foeb)								
MTBE								
Naphtha								
Alkylate								
Isomerate								
Hydrocrackate								
Reformate								
FCC Gasoline								
FCC Feed								
Vacuum Resid								
Other Unfinished Oils								
Other Inputs								

* Inventory drawdown refers to an inter-seasonal reduction in inventory.
Summer 1997 refers to the time period covering May 1 through August 31, 1997 (123 calendar days).

Company:

Refinery Location:

Table 9: Refinery Streams Sold or Stored (for non-summer use): Summer 1997

Description	Volume (bbl/sd)	Boiling Range (°F)	API Gravity	Sulfur (ppm)	Inventory Build*
Butanes					
Pentanes					
Naphtha					
Alkylate					
Isomerate					
Hydrocrackate					
Reformate					
FCC Gasoline					
FCC Feed					
Vacuum Resid					
Other					

Note: Excludes sales of refined products.
Summer 1997 refers to the time period covering May 1 through August 31, 1997 (123 calendar days).
* Inventory build refers to an inter-seasonal increase in inventory.

Company:

Refinery Location:

Table 10: CARB RFG Base Gasoline T50 Depression: Summer Season

Base Gasoline T50 Distillation Temperature (°F)	Percent Ethanol in Final Blend (vol %)									
	1	2	3	4	5	6	7	8	9	10
180										
185										
190										
195										
200										
205										
210										
215										
220										
225										
230										
235										
240										

Note: The purpose of this table is to obtain a sufficient number of data points to more accurately model the blending characteristics of ethanol with regard to the T50 suppresion effect on different types of CARBOB base gasolines.

Company:

Refinery Location:

Table 11: Additional Questions Regarding Refining Operations

1. What streams is your refinery fuel system now capable of handling (without regard to permitting issues)?

2. What feeds is your hydrogen plant now capable of handling?

3. What streams is your co-gen plant now capable of handling?

4. What class of gasoline (if any) would you expect to produce for Maricopa County, AZ starting in summer of 1999 (CARB RFG or Fed Phase 2 RFG)?